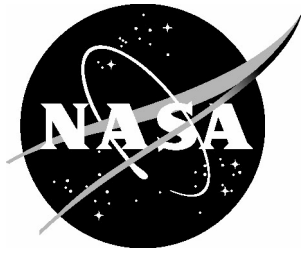


NASA/CR-2005-213759



Development of the Runway Incursion Advisory and Alerting System (RIAAS)

Research Summary

Rick Cassell

Rannoch Corporation, Alexandria, Virginia

May 2005

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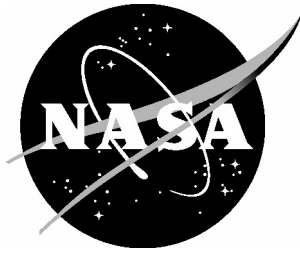
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ABSTRACT

This report is a summary of the research conducted during the development of the Runway Incursion Advisory and Alerting System (RIAAS). RIAAS was developed under a cooperative agreement between Rannoch Corporation and NASA Langley Research Center. The research and development has been under the auspices of the NASA Aviation Safety Program. RIAAS is part of the overall NASA Runway Incursion Prevention System (RIPS). Rannoch's name for the commercial product version of RIAAS is PathProx[®].

Rannoch has successfully developed an aircraft based runway incursion alerting system. Throughout the course of development RIAAS has undergone a series of tests. This includes flight tests conducted by NASA, flight simulator tests with airline subject pilots, and Rannoch tests with a computer simulation tool. The results of these tests have shown the following:

- The basic RIAAS design concept for runway incursion alerting is valid.
- Pilot feedback has been generally favorable. Several design changes recommended by the pilots have been incorporated into RIAAS.
- RIAAS alerting performance is such that the alerts are generally provided with sufficient warning to enable safe evasive maneuvers.
- All known incursion scenarios have been accounted for in the design.

In addition, a series of analyses have been performed related to RIAAS implementation. These included analyses of Safety Benefits, and Key Technical Issues. Most of the key technical issues have been addressed either in terms of system design or technical standard specifications. Monte Carlo simulations found that the risk of collisions due to runway incursions could be nearly eliminated with universal RIAAS equipage. The simulations and analysis also found that RIAAS provides significant improvement in runway safety with equipage for only the ownship aircraft.

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1.0 INTRODUCTION

This report is a summary of the research conducted during the development of the Runway Incursion Advisory and Alerting System (RIAAS). RIAAS was developed under a cooperative agreement with NASA Langley Research Center. The research and development has been under the auspices of the NASA Aviation Safety Program. RIAAS is part of the overall NASA Runway Incursion Prevention System (RIPS).

Airport surface incursions have been identified by the National Transportation Safety Board (NTSB) as one of the most significant safety hazards in civil aviation [Ref. 1]. RIAAS is being developed by Rannoch Corporation to help address this problem. (Note- Rannoch's name for the commercial product version of RIAAS is PathProx[®]) RIAAS is an aircraft-based runway incursion alerting system, and provides runway incursion alerts directly to the flight crews.

Much of the material contained in this report was previously documented in prior reports published throughout the development of RIAAS. Those reports should be referred to for more details on the research summarized here.

2.0 RIAAS FUNCTIONAL DESCRIPTION

RIAAS is designed to monitor aircraft that are either on the airport surface, or are within the airport's arrival and departure zones. The system initiates alert processing whenever an aircraft equipped with RIAAS (ownship) enters a runway zone, which includes the runway, intersecting taxiways, arrival and departure zones associated with the runway. The system uses Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B) to track other aircraft/ground vehicles (traffic) operating in ownship's runway zone. RIAAS is configured to issue alerts based on the states and proximity of the aircraft. The alerting logic is the core of the RIAAS algorithms. Figure 1 shows a typical aircraft implementation. RIAAS requires a method for annunciating the alerts. Alerts may be annunciated visually and/or aurally. A typical implementation would be to provide alerts on a CDTI (Cockpit Display of Traffic Information) and an aural annunciation to draw the flight crew's attention to the incursion situation (Figure 2). The implementation of RIAAS also requires an infrastructure outside of the aircraft (Figure 3). Optimum implementation would include a ground system that utilizes a combination of airport surface surveillance sensors. Aircraft and vehicle position information is then broadcast to the aircraft via TIS-B. However TIS-B is not required since RIAAS will operate using traffic information available from ADS-B equipped aircraft.

RIAAS is designed to handle approximately forty different runway incursion scenarios. Parameters such as position, speed, acceleration, heading, distance to hold lines, distance to runway thresholds, distance to runway edge, closure rate and separation distance are measured for every vehicle operating in the vicinity of the runway being used.

Calculations of each vehicle's dynamic state are compared against the alerting criteria, and an alert is issued if the criteria are met for one or more incursion scenarios. If multiple scenarios occur simultaneously, the one with the highest level of alert is used in determining which alert will be issued. Once evasive action has been taken and there is no longer a state of alert, the alerts are cleared from the display.

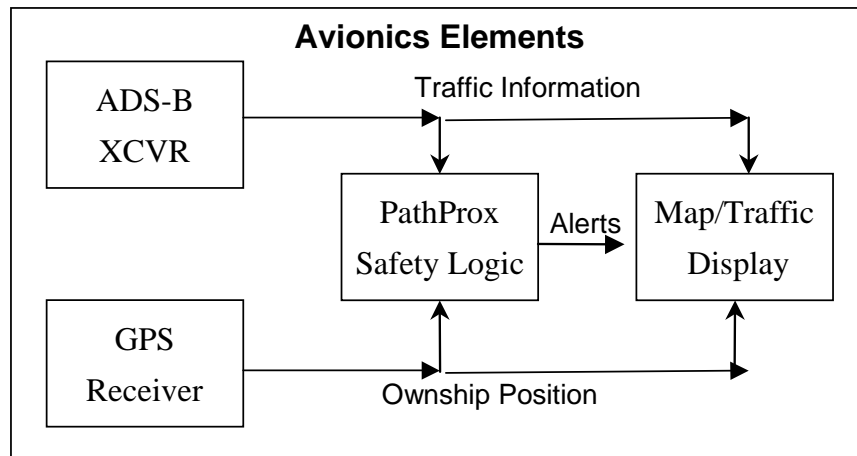


Figure 1. Avionics Systems Architecture



Figure 2. RIAAS Alert Display (NASA)

RIAAS provides two types of alerts, analogous to TCAS. A Runway Traffic Alert (RTA) is generated when the ownship aircraft is involved in a runway incursion with other traffic that is not critical. The RTA acts to caution the pilot of a potential incursion or an incursion where the conflict does not yet require evasive action. A Runway Conflict Alert (RCA) is provided when an actual runway incursion has been detected, and there is potential for collision. An RCA indicates that the aircraft involved in the conflict needs to take evasive action to avoid the potential collision. Unlike TCAS, RIAAS does not provide guidance information to the pilot for taking evasive action. The reason for this is that the number and complexity of the scenarios make it difficult to correctly identify the proper evasive action to take in every situation. Information that is provided with each alert includes identification of the incurring aircraft (or vehicle), the runway associated with the aircraft, and separation distance. Alerts are displayed on a moving map display tailored to the airport surface. This display should provide enough information to the pilot to determine proper evasive action.

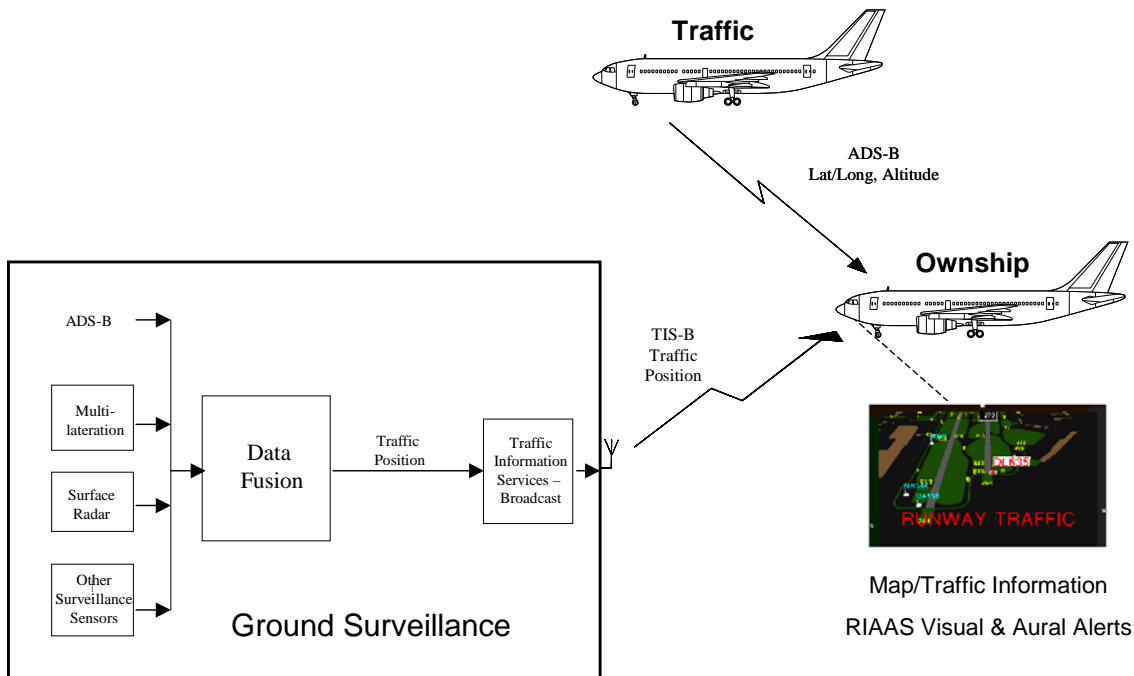


Figure 3. Systems Architecture

3.0 RUNWAY INCURSIONS AND RIAAS ALERTING

3.1 Runway Incursions Description

A runway incursion is defined by the FAA [Ref. 2] to be “any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground, that creates a collision hazard or results in the loss of separation with an aircraft taking off, intending to take off, landing, or intending to land.” The causes of runway incursions are classified in four types:

1. Pilot Deviations (PD) - An action of a pilot that results in violation of a Federal Aviation Regulation.
2. Operational Errors (OE) - An occurrence attributable to an element of the ATC system which results in:
 - less than the applicable separation minima between two or more aircraft, or between an aircraft and terrain or obstacles, as required by FAA Order 7110.65, Air Traffic Control, and supplemental instructions. Obstacles include vehicles/equipment/personnel on runways; or
 - an aircraft landing or departing on a runway closed to aircraft operations after receiving air traffic authorization.
3. Operational Deviations (OD) - Controlled occurrences where applicable separation minima, as referenced in the definition of operational error (see above) are maintained, but
 - less than the applicable separation minima existed between an aircraft and protected airspace without prior approval, or

- an aircraft penetrated airspace that was delegated to another position of operation or another facility without prior coordination and approval.

4. Vehicle/Pedestrian Deviations (VPD) - Incursions resulting from a vehicle operator, non-pilot operator of an aircraft, or a pedestrian who deviates onto the movement area (including the runway) without ATC authorization.

The FAA also categorizes incursions by their severity [Ref. 3]. There are four categories of severity, with Category A being the most severe and Category D the least. Following are descriptions of the categories:

Category A - *Separation decreases and participants take extreme action to narrowly avoid a collision.*

Category B - *Separation decreases and there is a significant potential for collision.*

Category C - *Separation decreases but there is ample time and distance to avoid a potential collision.*

Category D - *Little or no chance of collision but meets the definition of a runway incursion.*

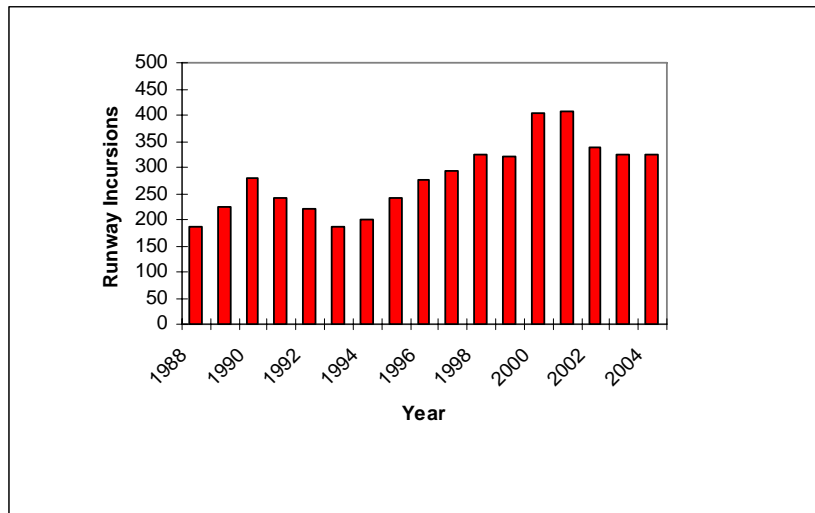


Figure 4. Number of Runway Incursions in U.S.

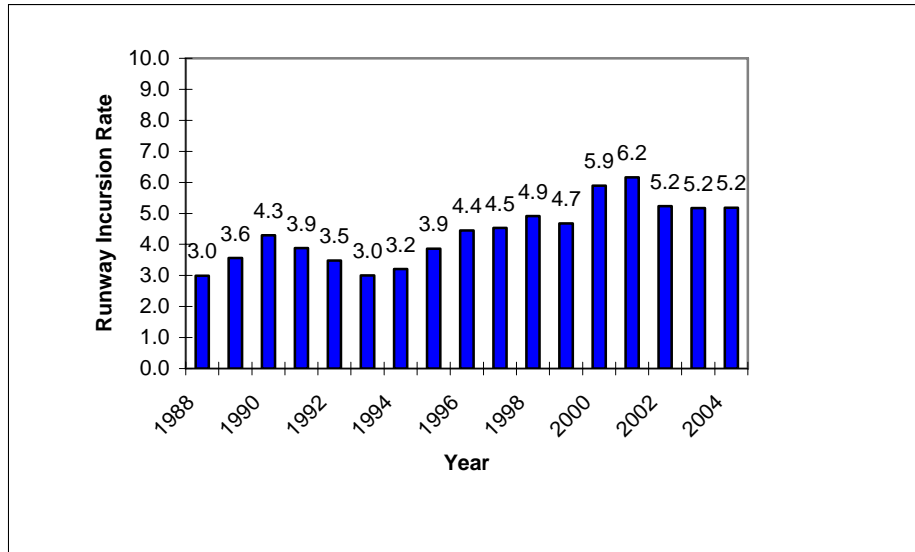


Figure 5. Rate of Runway Incursions in U.S. (per million operations)

The number and rate of runway incursions has remained relatively level over the last few years (Figures 4 and 5) [Ref. 3]. In addition to the increase in the total number, there have been a significant number of the most severe (Category A) incidents. For the years 2000-2003, Category A incidents comprised 4% of all incursions, with a total number of 59 such incidents (Figure 6). Category B incidents comprised 8.7% of all incursions, with a total of 129 incidents.

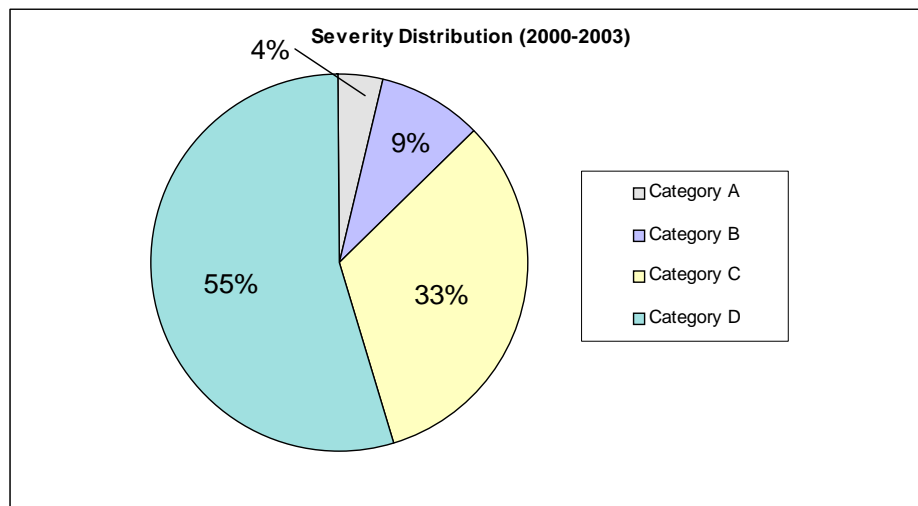


Figure 6. Distribution of Incursions by Severity Category

The severity of the incursion has been taken into account in determining the RIAAS alerting criteria. For incursion conflicts that fall into Categories C and D, RIAAS generally provides a Runway Traffic Alert. Since there is little chance of collision at the time of the conflict, there is no need to take immediate evasive action. It does however serve as a warning that there is potential for a more serious conflict. Category A and B conflicts meet the criteria for Runway Conflict Alerts because immediate evasive action is required.

3.2 Alerting in Specific Incursion Scenarios

RIAAS is designed to detect all possible runway incursion scenarios. Appendix B lists all of the combinations of scenarios according to the vehicle state categories used in RIAAS. Alerts are generated for all of these scenarios when conditions indicate a conflict.

4.2.1 Common Incursion Scenarios

Figure 7 depicts four of the most common scenarios. These account for over 70% of runway incursion scenarios [Ref. 4]. The scenario in Figure 7A is when an aircraft taxis onto an active runway while an arrival aircraft is attempting to land. The scenario in Figure 7B is also when an aircraft taxis onto an active runway, this time when a departing aircraft is attempting to takeoff. The scenario in Figure 7C occurs when there is a loss of separation between a departing aircraft and an arrival. The scenario in Figure 7D occurs when there is a conflict on a converging runway operation. This scenario can involve the use of Land and Hold Short Operations (LAHSO) on the converging runways. In these operations aircraft are allowed to land and hold short of the intersection of the converging runway, while allowing traffic to operate independently on the other runway.

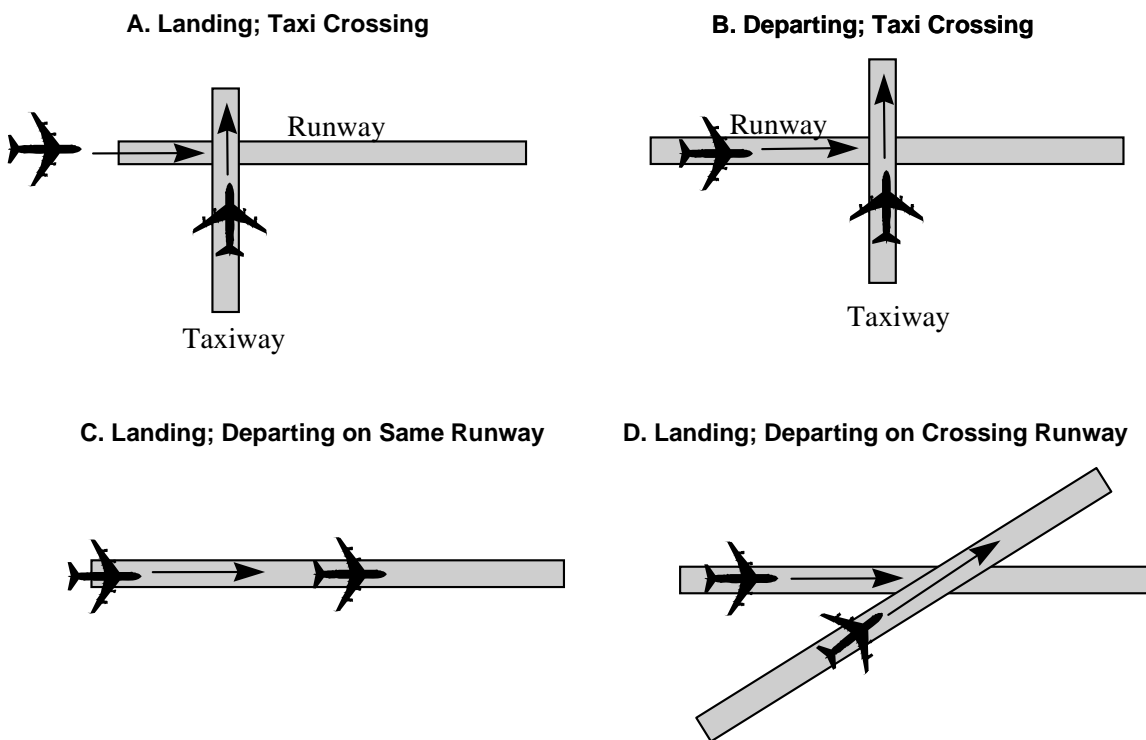


Figure 7. Common Runway Incursion Scenarios

3.3 Accident and Incident Incursion Scenarios

Following are descriptions of several accidents and incidents caused by runway incursions. Following each description is an indication of how RIAAS equipage (both aircraft) would have prevented the accident or incident from occurring.

Los Angeles International, February 1, 1991: A Sky West commuter aircraft was cleared by air traffic control to position and hold for takeoff on runway 24L.

Subsequently the local controller forgot about the commuter aircraft's position and cleared a US Air 737 for landing on 24L. The 737 crashed into the commuter aircraft, resulting in the loss of both aircraft and 34 fatalities [Ref. 5]. *RIAAS would have alerted well in advance of the landing such that the 737 could have safely performed a go-around.*

Detroit Metropolitan, December 3, 1990: A Northwest 727 was on its takeoff roll on runway 9 when it was struck by a Northwest DC-9, which had just taxied onto the active runway. The accident occurred in low visibility conditions due to dense fog. The DC-9 pilot was confused about his location and incorrectly taxied onto runway 9, causing a runway incursion and subsequently the accident. There were 8 fatalities and the DC-9 was destroyed [Ref. 6]. *The DC-9 would have received a RIAAS alert as soon as it crossed the hold line for the active runway, enabling it to stop prior to entering the runway. Similarly the 727 would have received a RIAAS alert shortly after starting its takeoff roll, enabling it to reject the takeoff.*

St. Louis Lambert, November 22, 1994: A TWA MD-82 was on takeoff roll on runway 30R when it collided with a Cessna 441, in holding position for takeoff. The Cessna pilot had caused a runway incursion by incorrectly believing that he was assigned 30R for takeoff, instead of runway 31, for which ATC had given clearance. The resulting accident resulted in 2 fatalities [Ref. 7]. *The MD-82 would have received a RIAAS alert shortly after starting its takeoff roll, enabling it to reject the takeoff and prevent the collision.*

Chicago O'Hare, April 1, 1999: A China Airlines 747 freighter landed on Runway 14R and was cleared to taxi to the cargo area. The crew apparently became confused and reentered the runway. A Korean Air 747-400, taking off on Runway 14R, flew over the China Airlines plane at less than 50 feet, as it was raising its landing gear. *The China Airlines 747 would have received a RIAAS alert after it crossed the runway hold line, enabling it to stop prior to entering the runway.*

Los Angeles International, November 22, 1999: An Aeromexico MD-80 failed to hold short of an active runway and wandered into the path of a departing United Airlines 757. The United pilot lifted the 757 off early and missed the MD-80 by approximately 60 feet. *The MD-80 would have received a RIAAS alert after it crossed the runway hold line, enabling it to stop prior to entering the runway.*

4.0 TEST RESULTS

4.1 Flight Tests – Dallas Fort Worth Airport

Flight testing of RIAAS was conducted during October 2000 as part of NASA's Runway Incursion Prevention System (RIPS). During these tests several incursion scenarios were simulated. The aircraft equipped with RIAAS was the NASA B-757 Airborne Research Integrated Experiment System (ARIES). A test van was used to simulate the other aircraft in the runway incursion. References 8, 9, and 16 contain the detailed test results. The flight tests demonstrated that the basic design of RIAAS provided proper alerting for the three incursion scenarios tested.

4.2 NASA RIPS Research Flight Deck Simulator Tests

4.2.1 RIPS Simulator Test Description

NASA conducted piloted simulations of the Runway Incursion Prevention System (RIPS) in a full mission simulator (Research Flight Deck) at Langley Research Center in March 2002 [Ref. 10]. The purpose of the study was to evaluate the RIPS airborne incursion detection algorithms (including RIAAS) and the associated alerting and airport surface display concepts. Eight commercial airline crews (16 pilots) participated as test subjects. The tests were conducted under various conditions, including VMC, low visibility (250 ft), and with the various cockpit technologies (incursion alerting, moving map, HUD) enabled or disabled. RIAAS alerted as designed during all of the RIPS simulator tests. The RTA and RCA alerts were generated at the appropriate (as designed) locations during the incursion scenarios. There were no missed alerts or false alerts observed during the testing.

4.2.2 RIPS Simulator Pilot Feedback

NASA conducted a survey of the subject pilots to obtain their feedback on the RIPS implementation. The results and comments relevant to RIAAS are summarized here. The pilots were unanimous in feeling safer with the RIPS technologies in the cockpit. Seventy five percent of the pilots thought that the alerts were timely, by allowing sufficient time for the pilot to react to the conflict. There were some specific issues on timing that are discussed in more detail below. Seventy five percent of the pilots also thought that the two stage alerting was beneficial. This validates one of the basic design concepts in RIAAS - providing both a traffic alert and conflict alert. A minority of the pilots thought that providing escape maneuver guidance would be beneficial. Specifically the percentages of pilots favoring maneuver guidance for each operational phase were: final approach – 25%; takeoff – 31%; taxi – 44%. This finding validated another basic design concept in RIAAS – providing alerts only and not escape maneuver guidance. This is thought to be primarily a training issue.

The pilots thought that the timeliness of the alerts was appropriate, with some exceptions. This feedback did result in several design changes as described in Section 6.7. Specifically, the feedback that identified the scenarios for some design changes was as follows:

- During scenarios where ownship is on approach the pilots indicated that the alerts should be disabled following initiation of the go-around because they are a distraction at that point. Consequently a design change was implemented so that during go-arounds (both ownship and traffic) all alerts are cleared.
- For scenarios where ownship is departing and there is an incursion by other traffic the time between the RTA and RCA was generally very short (2-3 seconds). The subject pilots indicated that in this case the RTA did not serve much purpose because the time difference was so short, and because the pilot would reject the takeoff upon annunciation of the RTA, without waiting for the RCA. A design change was implemented to provide single stage alerting for these scenarios.
- For scenarios where either ownship or traffic is stationary near the runway threshold, holding for takeoff, the subject pilots commented that the alerts should occur sooner than they did. The reason was that it is obvious very early in the

scenario that there is a conflict that can't be resolved quickly. For example, when ownship is the aircraft in the holding position it is unable to vacate the runway in a timely manner. Therefore the alerts need to be provided sooner to allow for adequate evasive action. A design change was implemented to modify the alert thresholds to provide earlier alerting in these scenarios.

4.3 GVSITE Flight Tests

RIAAS tests were done as part of the NASA Gulfstream-V SVS Integrated Technology Evaluation (GVSITE). Included among the GVSITE technologies was the NASA Runway Incursion Prevention System (RIPS), with RIAAS being one of the two incursion alerting systems. The tests were initially conducted in the NASA Research Flight Deck (RFD) flight simulator, using Wallops Flight Center and Reno/Tahoe International as the test airports. Flight tests were conducted later at both airports.

The primary focus for this set of tests for RIPS and RIAAS was evaluating the crossing runway alerting logic. Evaluation of RIAAS performance in all of the combinations of incursion scenarios indicates that the crossing runway alerting performed as designed. The testing validated the general design of the crossing runway alerting algorithms. The other new scenario tested was one intended to generate an alert based on a predicted violation of the taxiway hold line. This alerting was validated in the simulator tests. However the flight tests did not validate these alerts due to the way the scenario was conducted.

There were a high percentage of missed alerts, mostly due to a traffic ADS-B data interface problem on the G-V aircraft. One missed alert was due to a minor problem with the RIAAS logic. The remainder of the missed alerts were due to the way the scenarios were conducted, specifically the hold line prediction scenario. There was one scenario with a late alert, which was due to an ownship data issue. RIAAS alerted as expected in all of the runs (with the exception of the one with the logic issue mentioned above) that were not affected by the ADS-B data problems.

4.4 RIAAS Simulator Tests

4.4.1 RIAAS Simulator Description

The RIAAS simulator developed by Rannoch was used to generate the simulator results provided in this section. Reference 11 provides the detailed results for these tests. The simulations included the standard incursion scenarios, variable scenarios, and Monte Carlo scenarios. The RIAAS simulator generates tracks to be used for testing the RIAAS logic. The simulator provides a traffic display to show ownship and traffic position tracks. The display highlights the tracks involved in incursion alerts. The scenario database consists of the runway incursion scenarios that RIAAS is designed to process for alerting. In the simulation, Ownship performs evasive maneuvers in the event of a RCA (go-around, rejected takeoff, and emergency stop).

4.4.2 Standard Incursion Scenario Results

The fixed scenario is performed with a single run of ownship and traffic in real time. All of the incursion scenarios were run in the RIAAS simulator. Table 1 lists the results for six of these scenarios that are representative of nominal performance. The time-to-conflict is the time it would take for the two aircraft to collide, from the time of the alert. The separation distance is the distance between the two aircraft at the time of the alert. The RCAs nominally occur 25-35 seconds prior to a potential collision. This leaves

sufficient time to resolve the conflict. The RTAs nominally occur 10 seconds prior to the RCA.

It should be noted that this does not account for the variability of the timing of the scenarios. The actual relative location of the two aircraft when the conflict occurs is mostly a random process. Therefore the time to conflict and separation distances can be smaller or larger than those shown in Table 1. However, these summary results do indicate that in nominal scenarios RIAAS alerts provide warnings that will enable safe evasive maneuvers.

Table 1. Nominal Alerting Performance in Standard Scenarios

SCENARIO				RTA		RCA	
Scenario Pair	Ownship State	Traffic State	Conflict	Time to Conflict (sec)	Separation Distance (m)	Time to Conflict (sec)	Separation Distance (m)
1	Arrival	Taxi	Crossing	33	2300	26	1800
4	Taxi	Arrival	Crossing	33	2300	26	1800
7	Departure	Taxi	Crossing	NA	NA	32	1350
10	Taxi	Departure	Crossing	42	1500	33	1400
34	Arrival	Stopped	Head on	47	3300	37	2600
35	Departure	Stopped	Head on	52	1500	29	1250

4.4.3 Monte Carlo Incursion Scenario Performance

4.4.3.1 Monte Carlo Method

In a Monte Carlo scenario, multiple runs are performed, in fast time, whereby one or more parameters (i.e, relative aircraft timing or position) are varied randomly from one run to the next. The RIAAS simulator provides the capability to configure simulation parameters, such as Ownship start time, Traffic start time, taxi crossing point, pilot response delay, and system alert delay. When a value is varied, the simulation automatically performs multiple runs with a variable being changed from one run to the next. The reason for conducting a Monte Carlo simulation is to obtain an estimate of the alerting algorithm performance under conditions that are randomly varied. The Monte Carlo simulations were evaluated primarily by determining the number of cases that result in collision, near collision, or safe separation.

The simulator records closest separation and altitude between Ownship and Traffic. For this analysis, Ownship/Traffic encounters are categorized as follows, and as illustrated in Figure 8.

- Collision - Lateral separation less than 200 feet with and altitude separation of less than 100 feet
- Near Collision – Lateral separation between 200 and 300 feet with altitude separation less than 200 feet.

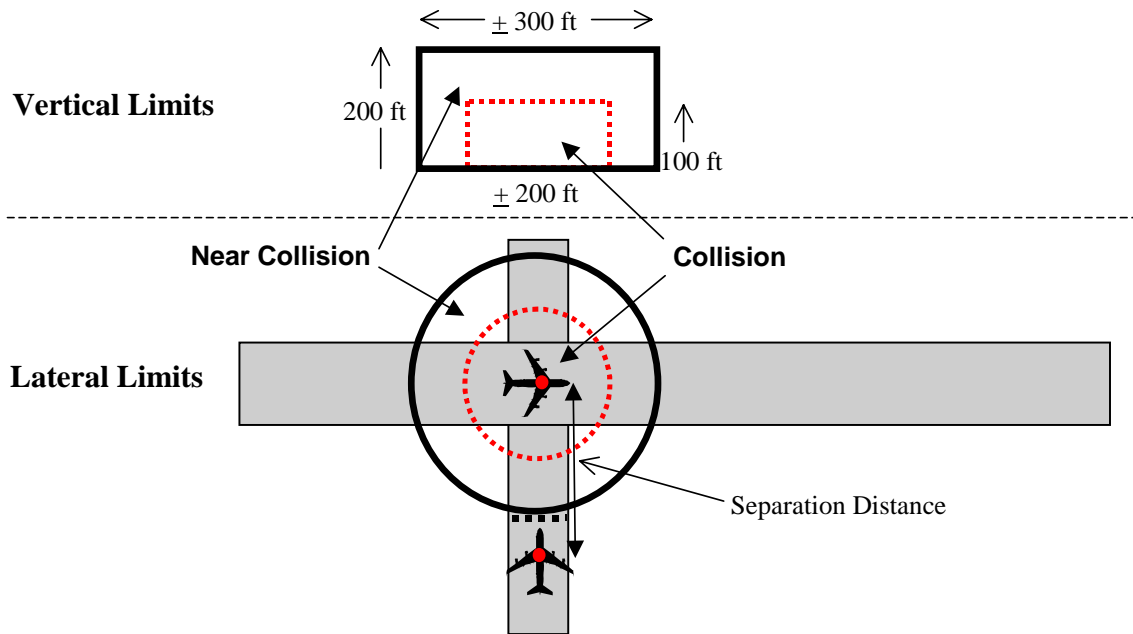


Figure 8. Runway Incursion Collision Criteria

4.4.3.2 Monte Carlo Simulator Scenarios

Monte Carlo simulations were done with the two most critical incursion scenarios – arrival/taxi crossing and departure/taxi crossing (Figures 9 and 10). They were conducted with both combinations of ownship and traffic simulating the two aircraft involved. They were then run with the evasive maneuvers (meaning RIAAS equipage) operational with ownship only, with both ownship and traffic, or with no evasive maneuvers. The cases where there are no evasive maneuvers simulates operations where RIAAS alerting is not available on either aircraft, which provides a baseline of the likelihood of collision without any alerting. Each scenario was run with a total of 10,000 samples.

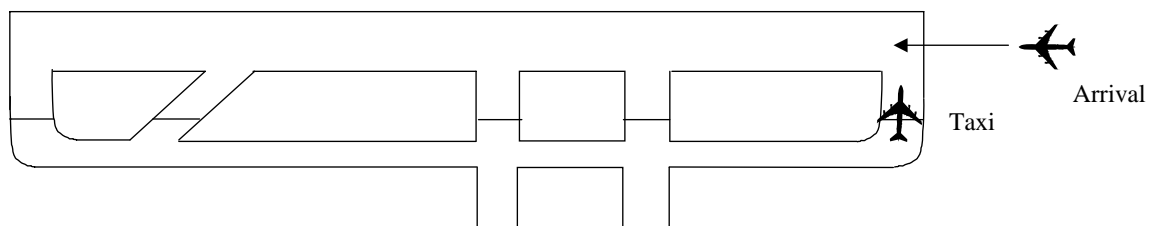


Figure 9. Approach/Taxi Crossing Incursion Scenario

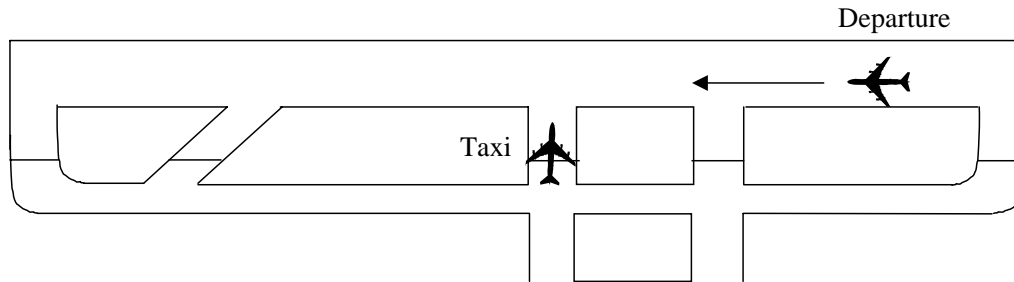


Figure 10. Departure/Taxi Crossing Incursion Scenario

4.4.3.3 Monte Carlo Scenario Results

Arrival/Taxi Crossing Results

The results of the Arrival/Taxi Crossing scenario simulations indicated that collisions were reduced from 12% to only 0.04% when the simulation was configured for both Ownship and Traffic to take evasive action on an RCA. There was also a significant overall increase in closest separation distances with evasive action on the RCAs. Results showed that the probability of collision is lower where ownship is the taxiing aircraft. The reason is that the pilot can stop the aircraft prior to entering the runway. When the ownship is the arrival aircraft, if the alert occurs during rollout, it still takes a significant period of time and distance to bring the aircraft to a stop. If the incurring aircraft creates an incursion while ownship is rolling out on the runway, there is likely to be a subsequent collision. This is the reason why RIAAS equipage on both aircraft is required to ensure a very low probability of collision in all cases.

Departure/Taxi Crossing Results

The results of the Departure/Taxi Crossing scenario simulations indicated the percentage of collisions was reduced from 19.5% to zero when the simulation was configured for both Ownship and Traffic to take evasive action on an RCA. Again, there was an overall large increase in closest separation distances with evasive action on the RCAs. As explained with the Arrival/Taxi Crossing cases the probability of collision is lower if the ownship aircraft is the one taxiing rather than the departure aircraft. Again, this is because the taxi aircraft can stop quickly prior to entering the runway, whereas the departure aircraft takes significant time and distance to stop if the alert occurs during takeoff.

5.0 SAFETY BENEFITS

5.1 Generic Safety Benefits

RIAAS provides several generic safety benefits with regards to the risks associated with runway incursions. One is that RIAAS does not rely on air traffic controller input. Providing the alerts directly to the cockpit (as recommended by NTSB) has the advantage of minimizing the delays in reporting alerts to the pilot. ASDE-3/AMASS provides surface traffic and runway incursion alerts to the ATC tower controllers. When an alert occurs and is reported to the tower, the controller must notify the flight crews involved in the incursion, so that they may take action to avoid a collision. However, the controller reaction time and voice communications delays cost valuable seconds in alerting the

flight crew. RIAAS also does not rely on ground systems to generate incursion alert messages. This makes it possible for equipped aircraft to reap the benefit of increased safety even when flying into airports that are not equipped with ground-based incursion prevention and detection systems.

Another generic benefit is improved pilot response to alerts. In addition to the reduced delays in alerting mentioned above, the pilot should also be able to take evasive action more quickly with RIAAS. This is partly due to the two stage alerting. Providing the Traffic Alert gives the pilot an indication of a potential conflict. By the time a Conflict Alert is generated the pilot should be aware of a pending conflict and the need for evasive action. Since it is assumed that the aircraft is also equipped with a moving map display with CDTI, the pilot should also have good situational awareness and be able to decide quickly on the optimum evasive maneuver.

5.2 Quantification of Safety Improvement

Following is a summary of the conclusions reached from the analysis of RIAAS safety benefits:

1. Implementation of RIAAS has the potential to reduce the risk of the most severe runway incursions (those that can result in a catastrophic accident - Category A and B) from the present rate of 1.2×10^{-6} to less than 10^{-9} per operation. This was based on the results of the Monte Carlo simulations.
2. The maximum safety benefit occurs at airports when there is no ground automated alerting and all traffic information is available to the aircraft equipped with RIAAS. In these situations RIAAS would provide the only incursion alerting function.
3. With ground surveillance and AMASS alerting available there is still a significant RIAAS benefit. This is due to more timely alerting than provided by AMASS, by eliminating the delays associated with the controller and communications. In addition, RIAAS provides more timely alerting on ownship due to having more accurate position and state information (heading, speed, acceleration, etc.) than is available to ground surveillance.

Any potential safety hazards associated with RIAAS would be related to the missed detection of runway incursion alerts and false alerts. Missed detections of incursions will be low enough that they will not impact the safety benefits. False alerts can result in unnecessary rejected takeoffs and go-arounds. The probability of RIAAS false alerts was found to be sufficiently low that it would not be an operational problem. References 12 and 18 provide more details on the safety benefits analysis.

6.0 KEY TECHNICAL ISSUES

Reference 13 contains the details of the analysis of key technical issues. Issues related to the implementation of RIAAS have been reviewed throughout development. The areas where technical issues remain are the quality of ADS-B and TIS-B traffic data, and optimization of two stage alerting and the associated alert criteria. The quality of traffic data can affect the performance of incursion alerting algorithms, particularly the likelihood of missed and false alerts.

Items that were reviewed and found to have no significant issues remaining are ownship data quality, operational acceptability of alert criteria, incorporation of all incursion scenarios, safety, and compatibility with ATC ground alerting. Many of the technical issues that were identified in the DFW flight tests and RIPS simulator tests have already been addressed by incorporation of design changes in RIAAS, described in Section 6.7.

6.1 Traffic Data Quality

Missing or erroneous ADS-B or TIS-B data is the most likely of the causes for a missed detection of an incursion. The NASA RIPS flight tests at DFW indicated several issues with the performance of ADS-B and TIS-B on the airport surface [Ref. 8, 9]. Erroneous data was manifested in several ways during the testing including incorrect position, speed, and heading data. Data link coverage was also an issue. One conclusion from the test evaluation was that incursion alerting logic performance is very dependent on the performance of the traffic position information. The information must be reliable, timely and accurate to ensure optimum runway incursion alerting performance. The ADS-B standards have addressed many of these issues in terms of the performance requirements [Ref. 14, 19].

Another issue is that TIS-B traffic data information has significantly longer latency than does ADS-B. Latencies of 2 to 6 seconds were observed in the TIS-B data recorded at DFW. This translates directly into delayed alerting on targets using position reports from TIS-B. It is assumed that the eventual implementation of TIS-B will have reduced latencies compared to those observed at DFW. However due to the inherent limitations in the processes involved it is doubtful the latency can be reduced below 2 seconds. Several features were added to RIAAS to address some of these issues, and are described in Section 6.7.

6.2 Aircraft Position Reference Point and Size

A key issue regarding traffic data concerns the ability to determine the location of the position information being broadcast via ADS-B, as well as the ability to determine the aircraft nose, tail, and wingtip. Since aircraft can have fuselage length and wingspans over 200 ft it is important for incursion alerting algorithms to be able to accurately determine the location of these points on the aircraft. A revision to the ADS-B Minimum Aviation System Performance Standard (MASPS) and Minimum Operational Performance Standards (MOPS) by RTCA includes changes to incorporate this information [Ref. 14, 19]. One change was to require that the position information broadcast be referenced to the “ADS-B Position Reference Point.” The second change was to define the aircraft dimensions according to size categories. These changes will enable incursion alerting algorithms to determine the location of the nose and tail of other aircraft with sufficient accuracy.

6.3 Alert Criteria

6.3.1 Two Stage Alerting

As described in Section 3, RIAAS provides two stages of alerting. The issues involving two stage alerting that were addressed during the research are: a) Is two stage alerting necessary; b) Is two stage alerting appropriate for all scenarios; and, c) Is the time between the two alerts optimum operationally.

a) Is two stage alerting necessary

The fundamental reason for two stage alerting is similar to that for other airborne alerting systems that have two levels of alerts such as TCAS and GPWS. The first alert (RTA) acts to caution the pilot of a potential incursion or an incursion where the conflict does not yet require evasive action. The second alert (RCA) is provided when there is potential for collision. An RCA indicates that the aircraft involved in the conflict needs to take evasive action to avoid the potential collision. Another reason for using two stage alerting relates to the severity of the incursion, which has been taken into account in determining the RIAAS alerting criteria. The FAA categorizes incursions by their severity as described in Section 3.1. For incursion conflicts that fall into Category D, RIAAS generally provides a RTA. Since there is little chance of collision at the time of the conflict, there is no need to take immediate evasive action. It does however serve as a warning that there is potential for a more serious conflict. The same logic applies to Category C. Category A and B conflicts meet the criteria for RCAs because immediate evasive action is required. Because of the large difference in severity depending upon the type of incursion, it is logical to provide two types of alerts with differing levels of criticality. As indicated in Section 4.2, the pilots generally support the concept of two stage alerting.

b) Is two stage alerting appropriate for all scenarios

The DFW flight tests and RIPS simulator tests have generally validated the concept that two stage alerting can be provided for the scenarios tested. One exception to this is the scenario where the conflict occurs while ownship is taking off. The time between the RTA and RCA is usually only a few seconds, and there are cases where the RCA occurred first. Generally the pilot is likely to initiate a rejected takeoff upon receiving either alert, so the two separate alerts are not necessary. As a consequence a design change was made to provide only an RCA for takeoff conflict scenarios.

c) Is the time between the two alerts optimum operationally

As shown in Table 1, the time between the RTA and RCA is generally on the order of 10 seconds. This should provide sufficient warning to the pilot about a pending conflict, and allow him to decide the proper evasive action, should an RCA be received. This was validated during the flight and simulator testing.

6.3.2 Operational Acceptability of Alert Criteria

The simulator testing conducted at Langley Research Center using airline subject pilots indicated that the pilots generally believed that the RIAAS alerts were operationally acceptable in terms of the timing. One scenario that some pilots commented on was one where the ownship was on the runway holding for takeoff, when another aircraft is on final approach, causing a loss of separation. Some pilots recommended that the alerts be generated sooner in that situation. A design change was made resulting in earlier alerts for that scenario.

6.3.3 Missed, Late, and False Alerts

Potential safety hazards associated with RIAAS are related to the missed detection of runway incursion alerts and false alerts. Missed detections of incursions can be a safety hazard. False alerts can result in unnecessary rejected takeoffs and go-arounds. The RIAAS safety analysis concluded that the probability of RIAAS false alerts was found to be sufficiently low that it would not be an operational problem [Ref. 12]. This was based

on the assumption that the traffic data was compliant with the associated performance standards.

The other aspect of late and false alerts concerns the incursion criteria used. The design must be optimized to balance the likelihood of both. If the criteria are relaxed such that zero false alerts occur, it is more likely that this will result in late alerts. Conversely, if the criteria were such that alerts occur as soon as possible, the number of false alerts would increase. One of the biggest factors is the accuracy of the surveillance data. The alert thresholds have to take into account position errors (as well as speed and heading) in ADS-B and TIS-B traffic reports. The alert criteria currently used in RIAAS take this into account and attempt to minimize the likelihood of false alerts. From a pilot and controller acceptance viewpoint the number of false alerts should be as small as possible, otherwise it could jeopardize the acceptability of RIAAS. Optimization of the alert criteria includes accounting for the difference in quality of traffic information.

6.5 Compatibility with ATC Ground Alerting

This issue concerns the compatibility of airborne incursion alerting with ground surveillance alerting systems, such as the FAA's AMASS (Airport Movement Area Safety System). It is likely that RIAAS and a ground system such as AMASS will not generate incursion alerts at the same time. The NASA DFW testing indicated that this is the case [Ref. 8]. The resulting question is whether this can cause any operational problems. RIAAS generally will alert sooner, primarily due to having more accurate position information. This means that pilots could take evasive action prior to the controller being aware of the conflict. The controller will then have to react to the evasive maneuver being taken and generate any other necessary instructions to the aircraft involved. This could cause some issues in the willingness of controllers to accept the system, who had to deal with a similar situation with the implementation of TCAS. However, the pilot always has the option of taking action to avoid conflicts with other aircraft, usually by visual means. The only difference with RIAAS will be that the pilot has an additional aid (including the moving map and CDTI) to inform him of conflicts. So in that sense this is not a change in operational procedures. Furthermore, the overall rate of incursions is low enough that the frequency of evasive actions will be extremely low. Another possible mitigation for this if it does become an operational issue would be for the aircraft to transmit runway conflict alert notification to Air Traffic Control. This could be done via the TIS-B or ADS-B data links. This would allow the controller to be aware of a conflict and enable him to provide instructions to the aircraft for evasive maneuvers. This capability was demonstrated by NASA as part of the DFW RIPS flight tests.

6.6 Airport Database

RIAAS requires an airport database to define the locations of runways and taxiways. The key elements necessary are the runway thresholds, runway edges, airport elevation, taxiway hold lines, and land and hold short locations. The key technical issues relative to the database are availability, accuracy, and integrity. The primary issue is simply having the information available. Currently aircraft do not have airport surface information available in an electronic database. An initial set of standards for the data have been completed by RTCA and are contained in DO-272 "User Requirements for Aerodrome Mapping Information" [Ref. 15]. The accuracy required for the various data elements

have been specified in DO-272. The requirements most applicable to RIAAS specify the 95% accuracy to be 1 meter for most data elements. This level of accuracy is good enough to eliminate database errors from contributing to late or false alerts generated by RIAAS. That is because the other errors in the system (ownship position, traffic position, etc.) are much greater than 1 meter. DO-272 categorizes the accuracy requirements as “fine,” “medium,” and “coarse.” The 1 m accuracy is associated with “fine.” Medium data elements specify the largest 95% accuracy to be 5 m. The minimum requirement for RIAAS should be “medium” data. However, there may be an issue regarding 5 m accuracy for the key data points. The alert thresholds may have to be relaxed in order to prevent a higher number of false alerts. This will reduce the effectiveness of RIAAS somewhat by resulting in later alerts.

Database integrity relates to the probability of either erroneous or missing data. DO-272 specifies a maximum error allowed. For the airport surface data points of interest in the “fine” category the maximum error is defined as either 2 or 3 meters. That will be sufficient to minimize any impact on RIAAS performance. DO-272 also recommends the integrity levels for some, but not all, data elements. For applications using “fine” data some are classified as critical, which has an associated probability of erroneous data of 10^{-8} . Applications using “medium” data do not have any integrity levels recommended. An issue here is ensuring that the data used by RIAAS has the appropriate level of integrity. The impact on RIAAS performance with erroneous data points is similar to that with reduced accuracy, namely late or false alerts. The RIAAS safety benefits analysis [Ref. 12] indicated that for integrity failures in aircraft position information the probability should be on the order of 10^{-5} to 10^{-6} . The airport surface data points should be similarly classified. That would be consistent with the definition of the “essential” integrity level in DO-272, which has a probability of erroneous data of 10^{-5} .

6.7 Design Changes

Following are some of the significant design changes made during the development of RIAAS that were determined to be necessary based on the findings from the research:

- During go-arounds (ownship and traffic) alerts are cleared
- Added alerts based on a prediction of hold line violation by taxiing aircraft (ownship and traffic)
- Added criteria for removing outliers and filtering traffic data (ADS-B and TIS-B)
- Changed to single stage only alerting (runway conflict) for scenarios where ownship is departing
- For scenarios where either ownship or traffic is stationary near the runway threshold, holding for takeoff, the alert thresholds were changed to occur earlier with the other aircraft (ownship or traffic) on approach.

SUMMARY

Under a cooperative agreement with NASA, Rannoch Corporation has successfully developed an aircraft based runway incursion alerting system called RIAAS. Throughout the course of development RIAAS has undergone a series of tests. This includes flight tests conducted by NASA, flight simulator tests with airline subject pilots, and Rannoch tests with a computer simulation tool. The results of these tests have shown the following:

- The basic RIAAS design concept for runway incursion alerting is valid.
- Pilot feedback has been generally favorable. Several design changes recommended by the pilots have been incorporated into RIAAS.
- RIAAS alerting performance is such that the alerts are generally provided with sufficient warning to enable safe evasive maneuvers.
- All known incursion scenarios have been accounted for in the design.

In addition, a series of analyses have been performed related to RIAAS implementation. These included analyses of Safety Benefits, and Key Technical Issues. Most of the key technical issues have been addressed either in terms of system design or technical standard specifications. Monte Carlo simulations found that the risk of collisions due to runway incursions could be nearly eliminated with universal RIAAS equipage. The simulations and analysis also found that RIAAS provides significant improvement in runway safety with equipage on only the ownship aircraft.

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APPENDIX A ACRONYMS

ADS-B	Automatic Dependent Surveillance - Broadcast
AMASS	Airport Movement Area Safety System
ARIES	Airborne Research Integrated Experiment System
ASDE	Airport Surface Detection Equipment
ATC	Air Traffic Control
CDTI	Cockpit Display of Traffic Information
DFW	Dallas-Fort Worth International Airport
FAA	Federal Aviation Administration
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HUD	Head-Up Display
LAHSO	Landing and Hold Short Operations
NASA	National Aeronautics and Space Administration
NM	Nautical Mile
NTSB	National Transportation Safety Board
OD	Operational Deviations
OE	Operational Errors
PD	Pilot Deviations
RCA	Runway Conflict Alert
RFD	Research Flight Deck
RIAAS	Runway Incursion Advisory and Alerting System
RIPS	Runway Incursion Prevention System
RTA	Runway Traffic Alert
TCAS	Traffic Alerting and Collision Avoidance System
TIS-B	Traffic Information Services - Broadcast
VMC	Visual Meteorological Conditions
VPD	Vehicle / Pedestrian Deviations

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